U.S. PATENT APPLICATION

Inventor(s):   Edwin W. O'BRIEN
Andrew R. IBBOTSON

Invention: SURFACE TOPOLOGY INSPECTION

SPECIFICATION

SURFACE TOPOLOGY INSPECTION

BACKGROUND TO THE INVENTION

This invention relates to the inspection of surface topology, and in particular to inspection of the surfaces of structural members subject to high stresses.

In structural members subject to high stresses, for example metallic or fibre reinforced plastics composite wings, the topology of the surface of the member can be of vital importance. In metallic bolted structures, for example, cold expansion of fastener holes can increase the fatigue life of the member many times by prevention of the formation of cracks emanating from hole walls. A standard method of cold expanding such holes involves drawing a mandrel through a split sleeve within the hole and expanding the sleeve to form a zone of compression in the material surrounding the hole. The effect of creating this zone of compression around the hole is to cause a volcano-like disturbance or eruption of the surface surrounding the hole, due to the Poisson effect. This surface disturbance or eruption can extend up to a radius from the hole edge. Contrary to general belief it has now been found that the extent of the Poisson volcano around the cold-expanded hole is directly related to the material properties of the member and to the degree of expansion applied to the hole, at least when such expansion is carried out in a controlled manner for example by the above mentioned method of drawing a mandrel through a split sleeve. The degree of expansion, eg. 1%, 2%, 3%, 4% etc. determines the

level of fatigue enhancement applied to the hole. A very fine
balance exists however between causing damage to the member,
eg. plate material, by over-expanding on the one hand, and
providing insufficient fatigue protection by under expanding
on the other. For this reason it is important to be able to
ascertain not only the presence or absence of cold expansion
of holes but also the degree of such cold expansion in order
to guarantee the integrity of structural members such as those
in modern aircraft structures.

DESCRIPTION OF THE PRIOR ART

In our US patent No. 5,619,327 we disclose a method of
detecting cold expansion of holes in such a structural member
as an aircraft wing. Unfortunately this method whilst
fulfilling a vital and pressing need in enabling the first of
the two above requirements to be determined, does not disclose
a method of achieving the second in a reliable and repeatable
way.

In addition, in the context of highly stressed composite
materials, the degree of damage caused to a structure by an
object impacting a surface of the structure can be easily
hidden by the phenomenon of barely visible impact damage.
According to this phenomenon structural damage can actually
increase with distance from a surface to which an impact has
occurred. The ability to ascertain the extent of such damage
by the inspection of the topology of the impacted surface
would be extremely valuable because a technique is available

using a comparison of surface damage area and ultrasonic C scan measurements to determine this.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a method of inspecting the topology of a surface of a structural member to ascertain the degree of cold working of metal immediately surrounding holes penetrating that surface and also to ascertain the extent of damage to impacted composite structures.

According to the invention there is provided a method of inspecting the topology of a surface of a structural member to determine the degree to which a known type of stress has been applied to the member, the method including the steps of providing a range of calibration samples of structurally equivalent members, the samples each having been subject to the known type of stress to a differing respective degree; supporting a Moiré grid in a position spaced from and co-extending with the surface to be inspected and at a small included angle to the surface; directing a source of light through the grid to strike the surface at an oblique angle thereto; viewing the surface through the grid in a direction substantially normal to the surface to view interference fringes and regions of distortion to the fringes, and measuring the extent of a said region of distortion and comparing the said measurement with equivalent measurements

taken for respective calibration samples to determine the degree of stress applied to the member.

By the term, "structurally equivalent" is meant a sample having the same type of structure, eg. reinforced in the same way, the same structurally relevant dimensions, eg. thickness of the sample, and being of the same material. The interference fringes comprise shadows of the grid projected onto the surface combined with lines of the grid as directly viewed by the observer, and the regions of distortion of the fringes correspond to disturbance to the topology of the surface caused by a said application of stress to the member acting via the Poissons effect.

The step of making a said comparison between the said measurement and equivalent distances measured for calibration samples of a member of the same type, relevant dimensions (for example thickness) and material, may include determining which sample exhibits substantially the same measured distance as the said member, and noting the degree of stress applied to that sample, which degree of stress will substantially correspond to the stress, eg. degree of cold working of a hole, applied to the said member.

The method may include the step of adjusting the small included angle, for example by using a micrometer adjuster, to provide substantially the same fringe density as for the equivalent measurements taken on the calibration samples. In this way consistency of measurement is ensured.

- 5 -

The line spacings of the Moiré grid are preferably substantially in the range 1 to 200 lines per mm. At a line spacing of 1 per mm the apparatus would be capable of detecting a major dent, for example, in a surface of a member being inspected. Apparatus having line spacing within the range of substantially 5 to 20 lines per mm is preferred and a line spacing of substantially 10 lines per mm is most preferred, giving good resolution and range of application.

The method preferably includes the step of providing a said source of light of a generally parallel nature, eg. from a collimated source, to provide a linear interference pattern so as to facilitate accurate measurements when the observer's eye does not quite view the surface normal thereto.

The step of providing the source of light may conveniently comprise providing a substantially point source of light, eg. a light emitting diode. Provided the observer views the surface substantially normal thereto little loss of accuracy in measurement will result when such a light source is used.

The step of viewing the surface substantially normal thereto may be ensured by providing an optical aid so to indicate to the observer. The optical aid may comprise a mirror facing the observer fast with the body, the mirror having a line indicator spaced therefrom in the direction of the observer whereby, when the observer views the surface substantially normal thereto, no reflection of the line indicator will be observable in the mirror.

The step of measuring the extent of a said region of distortion may comprise taking the greatest possible measurement across the region substantially in a direction of undistorted fringes from commencement of distortion on one side thereof to ending of distortion on the other side thereof.

Where the distortion to the surface comprises an annular region surrounding a hole in the surface, the step of measuring the extent of the region of distortion may comprise taking the measurement substantially in a direction of undistorted fringes from a periphery of a said hole to a point of fringe distortion farthest from the said periphery.

The said oblique angle is desirably either 45 degrees or 63.2 degrees to enable a convenient relationship between grating pitch and surface displacement to be formed. The angles of 45 degrees and 63.2 degrees provide particularly convenient relationships between fringe order, grating pitch and displacement resolution since the vertical displacement per fringe is given by the reciprocal of the grating pitch divided by the tangent of the included angle. Thus tan 45 = 1, giving a resolution of 1 per pitch and tan 63.2 is approximately equal to 2, giving twice the resolution.

The method may include the step of providing a sighting device, for example a graticule, for the observer, which sighting device may be centred upon a region of distortion, eg. the centre of a hole believed to be cold worked, to facilitate accurate taking of the said measurements.

The observer may view the surface via the medium of a camera so that images of the measurements taken may be recorded. And more preferably the camera comprises a high resolution, preferably digital, still camera to enable the best possible accuracy of measurement to be achieved, when recording. When a digital camera is used, results of measurements taken may conveniently be transferred to a computer, for example for image processing or for long term use. Such a computer may be programmed to search for particular shapes of curve representing commencement or ending of regions of distortion of the fringes. In this way consistency of measurement between calibration samples and the member under test may be better achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described by way of example with reference to the accompanying drawings of which:-

Figure 1 is a schematic sectional view of a structural member penetrated by a cold expanded hole having the method of the invention applied to it,

Figure 2 is a schematic perspective view of a structural member with carrier fringes being viewed through a Moiré grid set at an angle to a surface of the member,

Figure 3 is a side schematic view of apparatus according to the invention including a digital camera,

Figure 4a is a photograph of interference fringes distorted in the region of a 1.0% cold expanded hole through a

plate, taken on the exit face, showing measurement of the extent of distortion, according to the invention,

Figure 4b is a photograph of interference fringes distorted in the region of a 1.5% cold expanded hole through the same plate, taken on the exit face, showing measurement of the extent of distortion,

Figure 4c is a photograph of interference fringes distorted in the region of a 2.0% cold expanded hole through the same plate, taken on the exit face, showing measurement of the extent of distortion,

Figure 4d is a photograph of interference fringes distorted in the region of a 2.5% cold expanded hole through the same plate, taken on the exit face, showing measurement of the extent of distortion,

Figure 5a is a graph of measurement of hole periphery to farthest extent of fringe distortion plotted against percentage applied expansion of the hole using the method and apparatus of the invention, for the entry face,

Figure 5b is a graph of measurement of hole periphery to farthest extent of fringe distortion plotted against percentage applied expansion of the hole, for the exit face,

Figure 6 is a sectional view of a structural member of fibre reinforced plastics composite material displaying the phenomenon known as barely visible impact damage ("BVID"),

Figure 7 is a bottom plan view of hand held apparatus of the invention,

Figure 8 is an image photographed, using a digital still camera, showing impact damage to a composite panel, using apparatus of the invention,

Figure 9 is a top plan view of the apparatus of Figure 7, and

Figure 10 is a schematic side sectional view of apparatus similar to that of Figure 7.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Figures 1, 2 and 3, apparatus according to the invention is shown for use with the method of the invention. A structural member 1 having an upper surface 2 and a lower surface 3 is penetrated by an aperture 4 defined by a circular wall 5 (see Figures 1 and 3). The aperture 4 is surrounded by a Poissons volcano 6 on the upper surface 2 and 7 on the lower surface 3. Supported above the member 1 and at a slight included angle alpha thereto (Figures 1 and 2) is a Moiré grid 8 having a grid spacing of 10 lines per millimetre. Gridlines 9 are shown greatly exaggerated in both size and spacing for reasons of clarity in the drawings. In Figure 2 a micrometer angle adjuster 10 for the included angle alpha between the Moiré grid 8 and the upper surface 2 of the member is shown. The direction of viewing by an observer is shown by the arrows indicated. In each figure a collimated light source 11 is shown schematically.

In Figure 3 a digital still camera 12 is shown having a lens 13 directed at the upper surface 2 of the member through the Moiré grid 8.

In Figure 1 shadows 14 cast by lines 9 of the grid are shown which combine with dark lines 9 of the grid when viewed from above by the observer to produce combined interference and carrier fringes 15 to 24. In Figure 2 carrier fringes 25 are shown appearing on the surface, as they would do to the viewers eye.

Taking Figures 4a, 4b, 4c, 4d and 5a, 5b together, it can be seen how, for a given type of metal plate having perhaps 3 or 4 diameters of aperture therethrough, a relatively restricted calibration programme can be used to ascertain the amount of cold working (if any) applied to a structural member defining an aperture therethrough of known material and thickness and having a known hole diameter. In Figures 4a to 4d the structural member is a metal plate and the four photographs of Figure 4 show interference carrier fringes 25 having distortions thereto measured to ascertain the amount of cold working in each case. A distance is measured in each case from a point 26 on the periphery of the hole 4 to a position 27 where carrier fringe distortion first occurs. It will be noted that the distance increases in each figure as the degree of expansion is increased. The outer edge of the Poissons volcano, indicated by position 27 in each photograph of Figure 4 has been found to be very consistent, and when measurements are compared to comparative calibration samples surprising accuracy of measurement of the degree of cold expansion can be obtained.

Turning now to the graphs of Figures 5a and 5b constructed for calibration samples, it can be seen how measurements from point 26 to position 27 for the samples being tested can be read off the graphs to give an indication of cold expansion applied to the hole in each case.

Figures 6 and 8 may be considered together. Figure 6 shows in a sectional view how impact damage 28 can spread from an impacted surface 29 through the thickness of a fibre reinforced plastics composite member 30 to virtually destroy the integrity of the member in the region of the damage 28. It will be noted that the damage is barely visible on the impacted surface 29 but increases dramatically in size towards a rear surface 31.

Figure 8 is a plan view of an impacted surface 29 of an actual structural member shown photographically. Straight interference fringes 32 are shown to be distorted for a considerable distance extending outwardly from an impact damage site 33 of the impacted surface 29. The region of distorted interference fringes 34, although visible through the Moiré grating as shown in Figure 8 would be invisible to the naked eye upon inspecting the impacted surface 29. Each fringe represents 0.005 in surface displacement.

The method of the invention therefore provides reliable means to estimate the damage to a composite structure following a barely visible impact to a surface of that structure. Calibration curves may be produced relating surface damage area to ultrasonic C scan results to estimate

volumetric damage induced through the material thickness using the method of the invention. The surface damage area would be ascertained by measuring the area of the distortion of the fringes 34 surrounding the damage site 33.

Figures 7, 9 and 10 show hand held apparatus 36 according to the invention. The apparatus comprises a hollow body 37 of aluminium having a handle 38 carrying two buttons 39, 40. The hollow body has a first rectangular hollow tube 41 through which the observer views a surface being inspected via a Moiré grid 8 supported at a lower end 42 thereof. The Moiré grid is desirably pivotally mounted to the body 37 and adjustable via a micrometer screw, but this feature is not shown in Figures 7, 9 and 10, but is shown in Figure 2. If such a feature appeared on the embodiment of Figure 7 a lower rectangular frame 43 would be placed flat on the surface being inspected and the angle alpha which the grid would make with that surface would be adjustable with precision via the micrometer adjuster 10 shown in Figure 2. This angle alpha could then be made accurately to reflect the same angle alpha used for calibration purposes.

Supported just above the Moiré grid 9 is a sighting device 44 comprising a needle 45 supported in spaced relationship to a mirror 46. When the surface of the member being inspected is viewed directly perpendicularly by the eye of the observer no reflection of the needle 45 will be seen by the observer in the mirror 46. In this way consistency of

measurement can be achieved to enable accurate comparison with
the calibration sample results.

Referring to Figure 9 an upper portion 47 of the
rectangular tube 41 is tapered to cut out as much extraneous
light from the interior of the apparatus as possible. This
feature is extremely useful in brightly lit shop floor
environments where it would otherwise be difficult accurately
to detect the interference fringes viewed through the Moiré
grid.

The apparatus also includes a second rectangular tube 48
set at an angle to the first tube. The second tube carries
two white 3.6 volt LED light sources 49, 50 acting
substantially as point light sources. Buttons 39 and 40 are
used individually to switch on the LEDs 49, 50, respectively.
It will be observed that LED 49 is designed to shine at an
angle of substantially 45° (alpha) to the surface being viewed.
LED 50 makes an angle of substantially 63.2° with the said
surface. The tube 48 also carries a battery pack 51 of three
1.2 volt nickel cadmium cells. The apparatus of the invention
is thus totally self-sufficient which makes it particularly
suitable for use on the shop floor when, for example,
structural members contained in aircraft wings are being
viewed. With the apparatus of the invention holes in
structural wing members may be tested for cold expansion and
compared with calibration samples of the same material and
thickness having known amounts of cold working carried out to
them. Thus for example if a crack has been detected in a

surface of the wing structure it can be determined with accuracy the extent to which any hole from which the crack emanates has been cold worked, and in particular whether it has been cold worked to the specified degree. Through a viewing aperture 52 formed in the top of the tapered portion 47 of the tube 41 can be seen a graticule 53 and an aperture 4 in a surface being viewed. The graticule is centred on the aperture. Using the graticule, the distances between points 26 and positions 27 as aforesaid can accurately be read off.

It will thus be seen that the apparatus and method of the invention provide convenient and reliable means accurately to obtain measurements of the degree of cold working of holes in metallic structures and impact damage to composite structures.